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# Earth observation with satellites

### Data processing and application examples

**Since 1972, Earth observation satellites have been supplying large amounts of data which give us a unique opportunity to observe land areas, the oceans, ice regions and the atmosphere. The following article illustrates the knowledge which can already be gained from these data today, with the applications mainly concentrating on climate and environment-related issues.**

The very large amounts of data transmitted by a satellite require appropriate data processing systems. The German Aerospace Research Establishment (DLR) has set up the German Remote Sensing Data Centre in Oberpfaffenhofen for this purpose. This Centre receives the data (e.g. from the NOAA satellites) either directly or via the European data network. The data are processed in Oberpfaffenhofen, archived and made available to users. In addition, there is a data receiving station in Neustrelitz, where most of the data available are from the Soviet Kosmos satellite series. Examples of various sensors and satellites are shown below *(Fig. 2)*. The data differ in terms of their geometrical resolution, in particular. The resolved pixel size varies between 5 m and 1.1 km.

For instance, *Fig. 3* shows a photographic image of the City of Berlin and its environs. The photograph was taken in August 1985 from a satellite of the Soviet Kosmos series at an altitude of 275 km. The KFA-1000 camera used for this purpose produces what are probably the best optical images of their kind. The resolution is better than 5 m. The infrared false-colour image shown was calibrated in such a way that vegetation appears in a realistic green shade. The former border installations between East and West can be seen, for example. Today, these areas are also largely covered by vegetation. The Adlershof Research Centre can be seen at the bottom right, between the railway line and the Teltow Chanal. Similar photographs of the whole of the former GDR, taken in the last five years, are available.

*Figure 4* is a product of the KATE camera, which records synchronous images in three spectral channels. This example dates back to August 1986 and is a colour composite produced from two spectral channels, one in the visible red range (600 to 700 nm) and one in the near infrared range (700 to 800 nm). The two images were combined using an analogue colour-mixing projector. The synthesised colour picture shows the central German loess region between Magdeburg and Leipzig. Green areas come up red in this picture. The ground resolution is 20 m and the area covered measures 100 x 150 km. Pictures of this kind give an overview of the structure of land usage at the time of the flyover. Arable areas with sugar beet, maize and potatoes are easily distinguishable. The meadows on the River Elbe and its arms are also clearly visible. A chronological sequence of such pictures can be used to document changes in land usage and forest damage. *Figure 5* shows a sub-area in the "Hoher Fläming" region, some 20 km to the North-West of the Luther town of Wittenberg. The pine forests are shown in dark green, mixed forests in medium green and deciduous forests in light green. Open arable land and settlements are yellow or dark blue in colour. This photograph was classified according to various degree of forest damage, see *Fig. 6*. Every pixel corresponds to an area of 30 x 30 m. Data of this kind are periodically updated and are available in an environmental database in Cottbus. Even better resolution is possible using the Daedalus scanner on board an aircraft at an altitude of 300 m. *Figure 8* shows an analysis of the multispectral data of this scanner for a region in the Fichtelgebirge mountains. The photo-

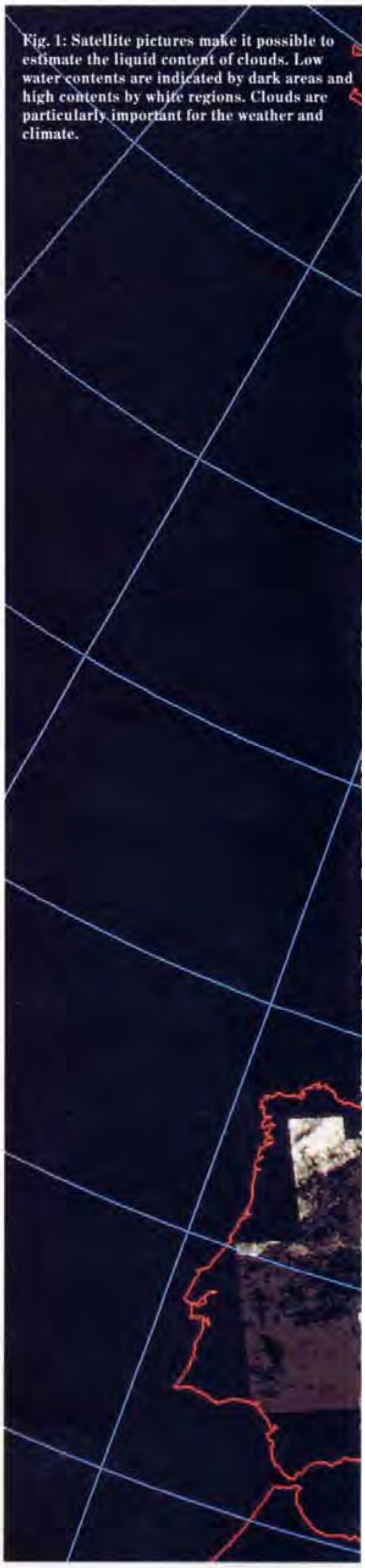
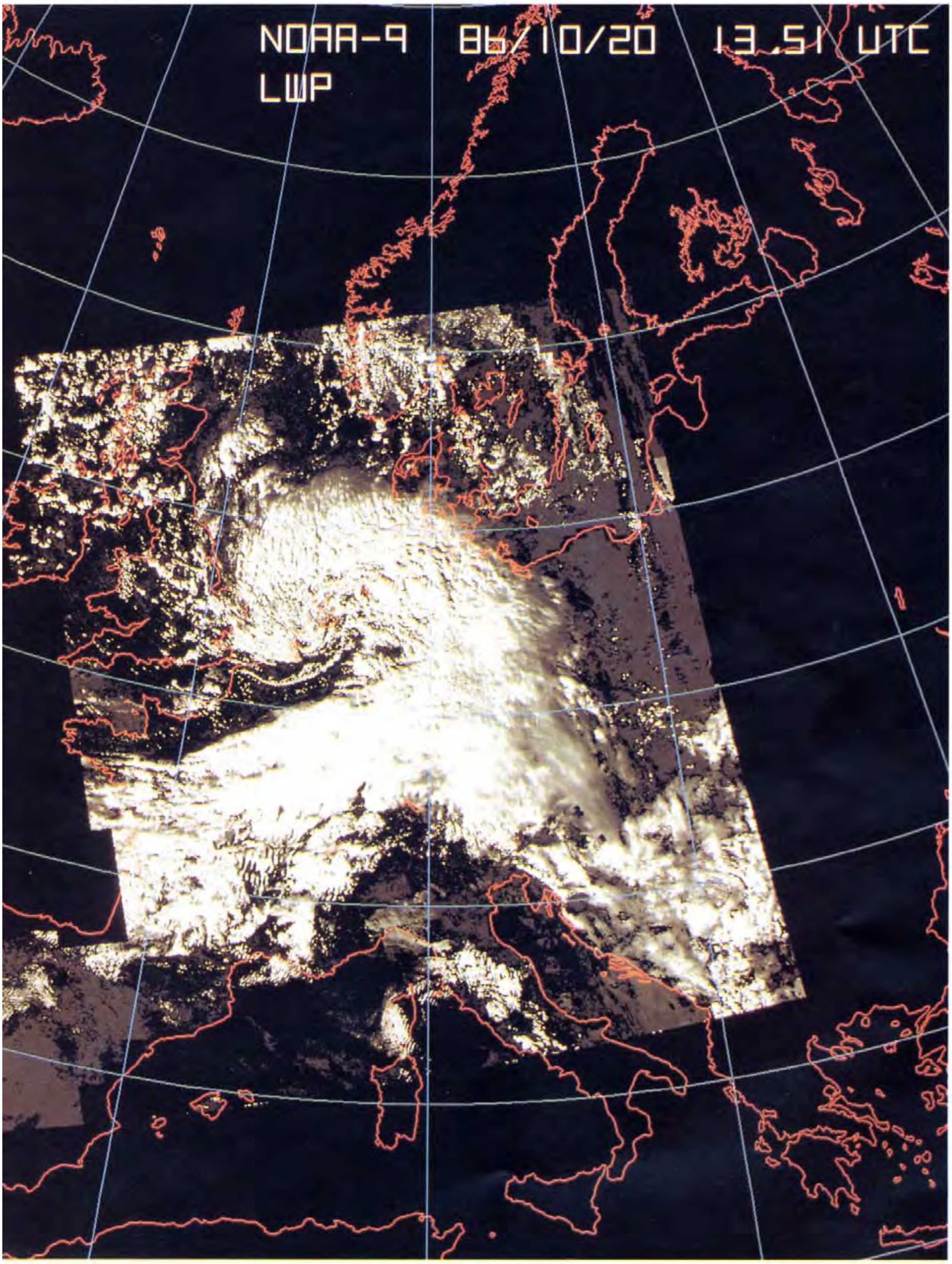


**Fig. 1: Satellite pictures make it possible to estimate the liquid content of clouds. Low water contents are indicated by dark areas and high contents by white regions. Clouds are particularly important for the weather and climate.**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LWP

**Examples will be shown from**

| Sensors/Satellite | Resolution |
|---|---|
| Camera KFA-100/Kosmos | 5 m |
| 3 Channel camera KATE-140/KOSMOS | 20 m |
| Thematic Mapper (TM)/LANDSAT | 30 m (80 m) |
| AVHRR High Resolution Radiometer/NOAA | 1.1 km |

**Fig. 2: Resolution of different sensors and satellites.**

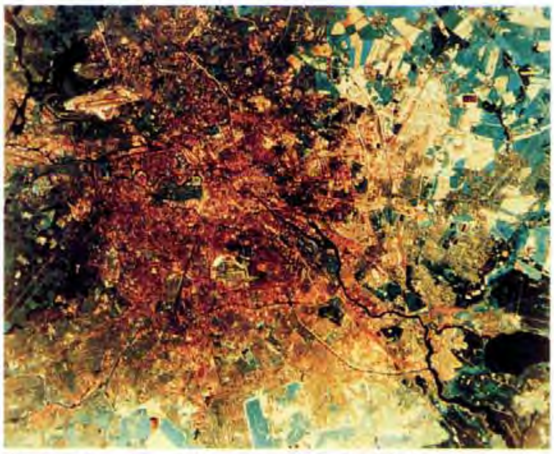


**Fig. 3: Berlin and its environs. Taken by the KFA-1000 camera in August 1985.**

graph shows the result of classification according to types of tree and damage classes of pines.

Such detailed analyses are not yet possible using the satellite data available today. However, as shown in *Fig. 9*, changes in forest coverage can be derived from LANDSAT data, which are available with a resolution of 80 m or, since 1984, 30 m. A 7.5 x 7.5 km section of the Fichtelgebirge image at the top left is shown at the bottom left. This LANDSAT-TM scene dates back to July 1984. The scene at the top right shows the same area with a resolution of 80 m and is based on a LANDSAT image taken with the old MSS scanner in September 1980; the picture at the bottom right is the corresponding TM image recorded in July 1986. The progressive loss of forest areas can be seen from these photographs. This application demonstrates the value of data archives containing comparable observations covering extended periods of time.

This is further evidenced by *Fig. 7*, where three LANDSAT scenes document changes in the tropical forest surrounding the City of Sena Madureira in the State of Acre in the South-West of the Amazon Basin in Brazil. The black areas represent the cleared forest regions in 1975, 1984 and 1989. This is the provisional result of an ongoing project with Brazilian colleagues, the objective of which is to quantify not only cleared areas, but also newly growing, secondary wooded areas. In a further stage, ERS-1 data are to be used to identify forest clearings on a larger scale.

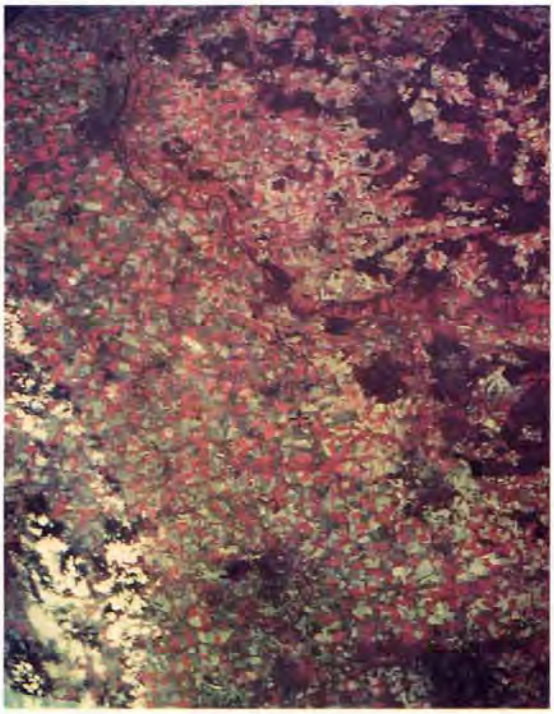
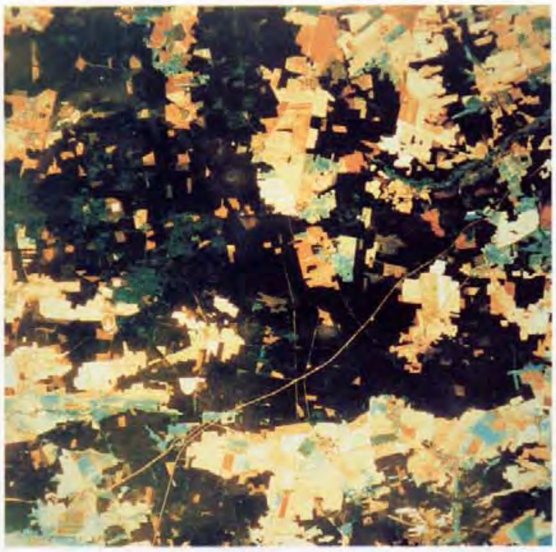
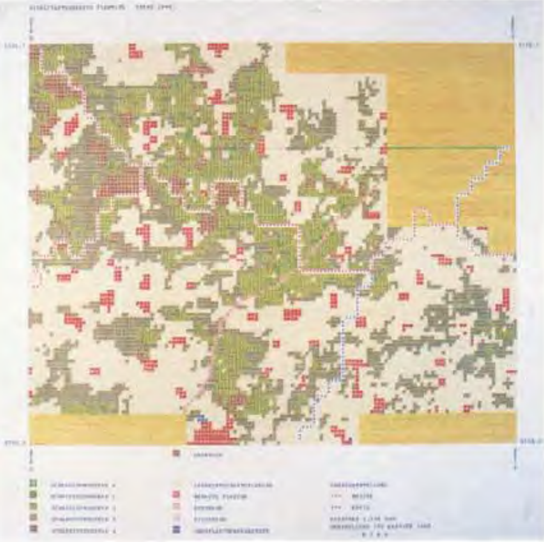


**Fig. 4: Central German loess region, taken by the KATE camera in August 1986.**

Maps which are of great practical use are obtained by combining LANDSAT data with topographical maps. Figure 10 shows the example of a forest map of a region near Regensburg. Five colours have been used to distinguish between different types of forest. Maps of this kind form the basis for registering the extent of forests and their changes, as well as damage classes.

A new class of information is obtained by combining LANDSAT data with high- resolution terrain data files and geological maps. As shown in *Fig. 11*, for example, this makes it possible to identify areas which are subject to a particularly great erosion risk. Thus, the bottom right-hand section of the picture





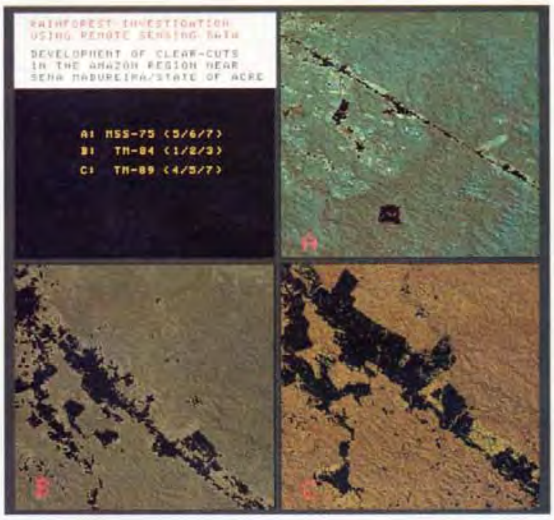


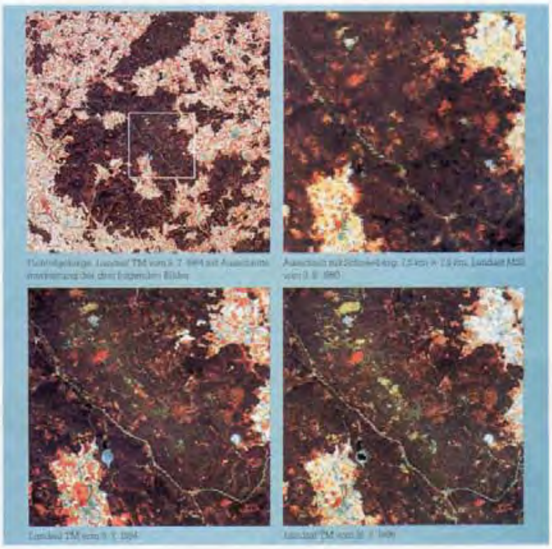

**Fig. 5 (top left): Part of the "Hoher Fläming" region, 25 km north-west of Wittenberg.**

**Fig. 6 (top right): Classification of Fig. 5 according to different forest damage classes.**

**Fig. 7 (right): Changes in the tropical forest in the area around the Brazilian city of Madureira, documented in a LANDSAT scene.**

**Fig. 8 (bottom left): Analysis of the multispectral data of the Daedalus scanner for a region in the Fichtelgebirge mountains.**

**Fig. 9 (bottom right): Changes in the forest coverage in the Fichtelgebirge mountains, derived from a LANDSAT-TM scene.**

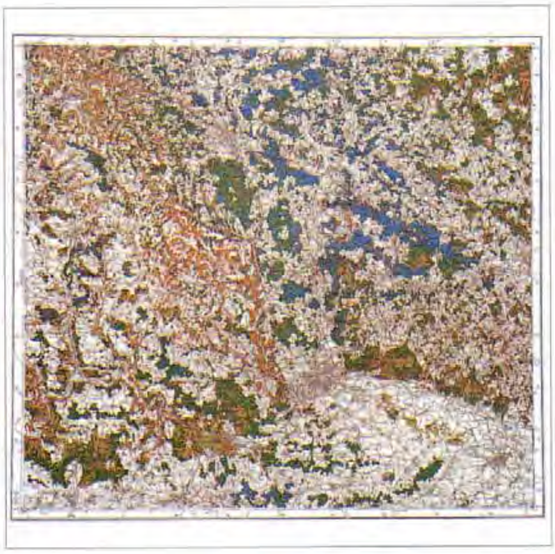


**Fig. 10: Forest mapping of an area near Regensburg. An example of the combination of LANDSAT data with topographical maps.**

**Fig. 11: Example of the combination of LANDSAT data with products of a high-resolution digital terrain model.**

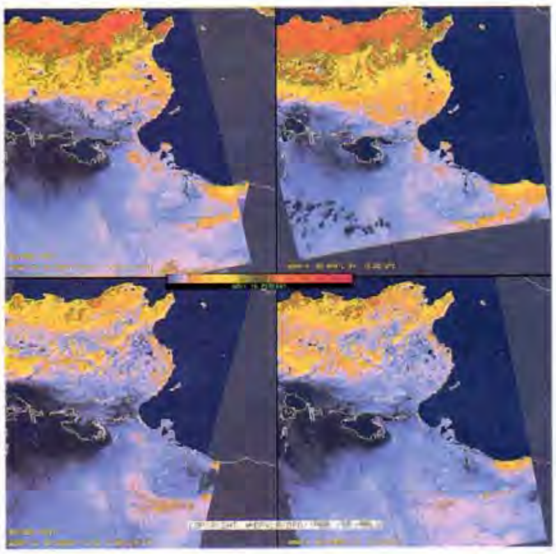


**Fig. 12: Determination of the vegetation index from satellite images. Changes in the vegetation index on the edge of the Sahara in Tunisia between 1984 and 1985.**

identifies wooded areas with an inclination of more than 30°. A series of photographs of this kind can be used to produce computer films showing the world in the way an observer flying over the area would see it.

Larger areas of the Earth can be analysed with the aid of data from the NOAA AVHRR sensors. The DLR has been receiving and archiving data of this kind since 1980, in conjunction with a network of receiving stations in Maspalomas, Tromsö, Dundee, Lannion and other locations. Within the framework of the so-called Earthnet of the European Space Agency (ESA), these data become part of the international "Tiros Network". In *Fig. 12*, the so-called vegetation index was determined from this kind of data. In this context, use is made of the fact that the chlorophyll in plants absorbs relatively strongly in the visible red range of the spectrum, but only very slightly in the near infrared range. Consequently, the difference between the albedo values from AVHRR channels 2 and 1, normalised with the sum of the corresponding values, yields a measure of the vegetation density. This picture shows the changes in the area of vegetation on the edge of the Sahara in Tunisia between the start (top) and end (bottom) of the dry season in 1984 (left) and 1985 (right). The area of depleted vegetation (blue) on the Northern edge of the Sahara is particularly large in the dry year 1984 as compared with the wetter year 1985.

We shall now leave the field of applications relating to land surfaces and turn to examples of remote sensing of ocean surfaces. *Figure 13* is again the product of NOAA AVHRR satellite data processed at the DLR. The objective here was to detect algae in the Northern Adriatic along the Italian coast from Trieste to Ancona in July 1989. In this picture, algae differ from the clean (dark blue) water in that they are blue-green or green to yellow in colour. However, these data do not permit a distinction to be made between algae and other suspended matter in the water. This would require better spectral resolution, as offered by CZCS in the past or ROSIS in future. In the case in question, water samples taken at the same time confirmed that the Adriatic was indeed polluted by algae. Aircraft-based observations using the Daedalus scanner provide a more accurate picture. *Figure 14* shows a 5 x 5 km scene on the coast at

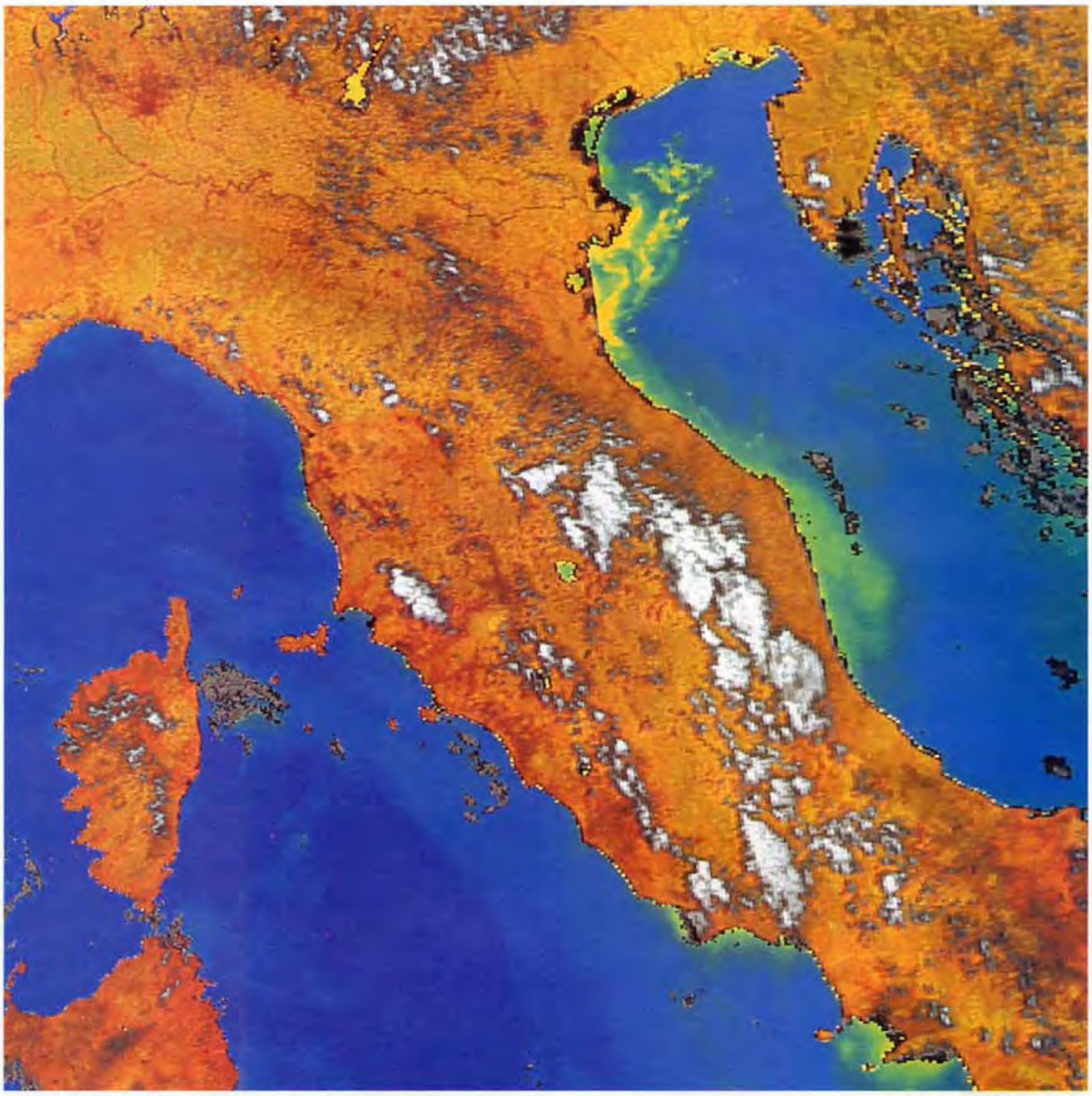


Fig. 13: Documentation of algae in the Northern Adriatic in July 1989 by means of satellite pictures.

Rimini in summer 1989, taken from an altitude of 3000 m. What is shown is the ratio of the green to the blue spectral channel (550 nm/450 nm), this ratio reacting particularly sensitively to the presence of algae.

*Figure 15* illustrates another important application – the evaluation of the sea surface temperature from NOAA AVHRR data. The surface temperature is one of the most important physical parameters controlling the exchange of

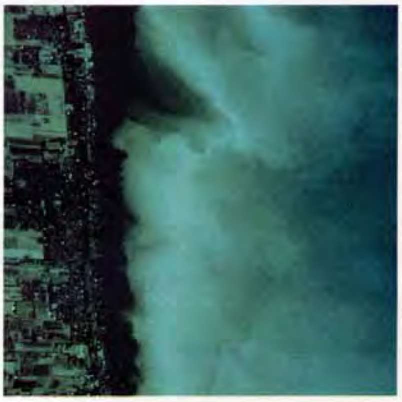


Fig. 14: The Rimini coast in Summer 1989. Aircraft-based observations with the Daedalus scanner complement the satellite observations in Fig. 13.

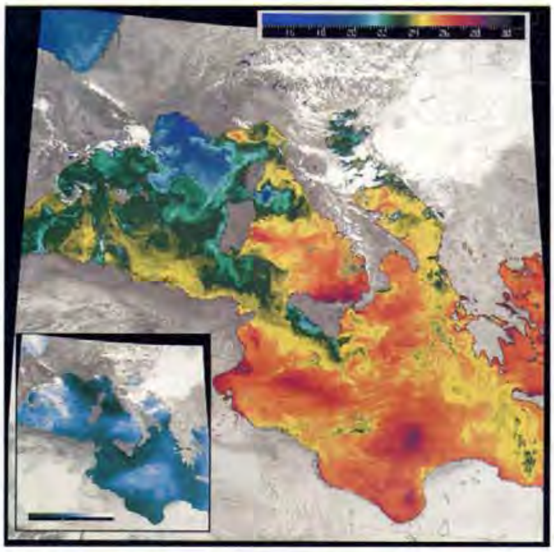


Fig. 15: Determination of ocean surface temperatures from NOAA AVHRR data.

Fig. 16: Clouds are particularly important for the weather and climate. This picture shows the combination of NOAA AVHRR data from three channels.

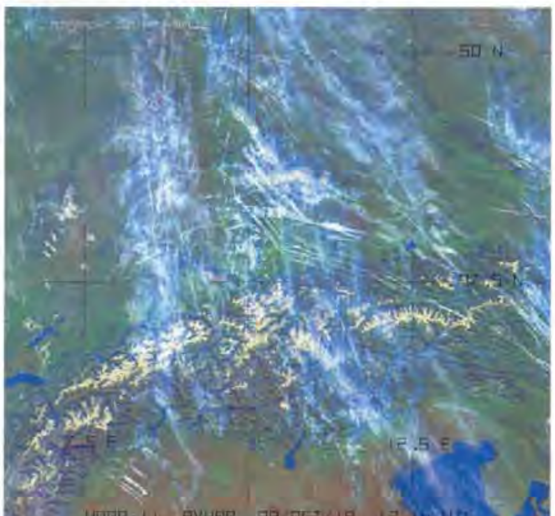


Fig. 17: Contrails in the satellite picture of the region between Frankfurt and Venice.

water vapour and energy between the surface of the sea and the atmosphere. In the absence of cloud cover, this temperature can be determined to within approx. 1 K from the data. This is done using the so-called split-window algorithm on the basis of the radiation temperatures in channels 4 and 5 which have spectral sensitivities in the region of 10 and 12 µm. The picture shows the greater part of the Mediterranean between Spain and Greece in a polar-stereographic projection. The land surfaces and most of the clouds are grey/ white in colour, in line with the dominance of the near infrared channel. The colours of the water surfaces correspond to the radiation temperature of the surface skin of the sea. The colour scale assigns the different colours to temperatures in degrees Celsius. Substantial temperature contrasts can be seen, some of which correlate with the oceanic currents.

The inset at the bottom left represents the difference between channel 5 and the calculated temperature. The slight variations to be seen there are typical for the effects of atmospheric water vapour, and this picture thus proves that disturbing atmospheric effects were largely eliminated here.

Clouds are of the utmost importance for the weather and climate. *Figure 16* shows a colour picture of the cloud cover, generated from AVHRR channel 1, 2 and 4 data in October 1986. This scene was processed using the so-called APOLLO algorithm, which was developed by British and German scientists and allows the liquid water path (LWP) of the clouds to be estimated. *Figure 1* shows the same scene, where dark areas are indicative of low water levels and white areas of high contents. These results were compared with numerical weather forecasts from the German Weather Service (14-hour forecast), and it was found that the results of the computer program exceeded the observed LWP values by a factor of up to 3. The German Weather Service is currently implementing the APOLLO procedure in its operations.

Air traffic causes artificial cirrus clouds in the familiar form of contrails. These thin clouds of ice can be detected using the difference between AVHRR channels 4 and 5, as the emissivity of ice clouds differs widely in these channels. *Figure 17* shows the region between Frankfurt and Venice, which is quite

**LIDAR** (Light Detection and Ranging)

- Aerosols
- Cloud height
- Boundary layer height
- Trace gases, e.g. water vapour
- Wind

**RADAR**

- Cloud water
- Precipitation
- Wind

**Fig. 18: Lidar and radar will increasingly be used as remote sensing systems in future.**

clearly covered by numerous linear contrails. It is estimated that on this day, 18 October 1989, some 8% of this region was covered by aircraft-induced clouds. This is an extremely high degree of cover. As far as we know so far, the average degree of cover over all days is about 0.4%.

The examples given up to now have come from passive remote sensing. In future, increasing attention will be paid to active remote sensing systems, such as lidar and radar *(Fig. 18)*. At the moment, these systems are used for remote sensing from the ground or from aircraft. Lidar systems are to be installed on one of the planned polar platforms at some time in the future. A lidar is also being prepared for the Soviet MIR station. An active remote sensing system of this kind can, in particular, provide information on the height and spatial distribution of clouds and aerosols with hitherto unknown accuracy. Cloud height is a critical parameter in relation to the climate. Changes in the aerosol concentration mainly occur at the upper edge of the convective atmospheric boundary layer. This fact is clearly illustrated in *Fig. 19*, which shows the light intensity backscattered by aerosols in a vertical cross-section of some 3 km in height and 10 km in length. This picture was derived from lidar measurements taken from an aircraft at an altitude of approx. 4 km and clearly shows the upper edge of the boundary layer. A new differential absorption lidar makes it possible to determine the water vapour concentration in absolute terms at the same time. The picture shows low water vapour concentrations (roughly 1 $g/m^3$) above the convective boundary layer and substantially higher values (5 to 7 $g/m^3$) inside it. Measurements of this kind are very important in helping

**Fig. 19: Lidar measurements from an aircraft. Changes in the aerosol concentration occur mainly at the upper edge of the convective atmospheric boundary layer.**

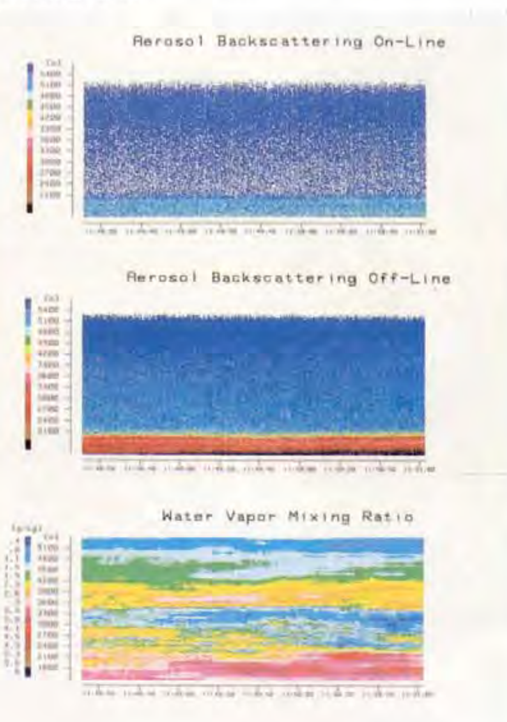



**Fig. 20: Radar of the Institute for Atmospheric Physics of the DLR.**

us to understand the hydrological cycle in the Earth's climatic system.

Like lidar, radar is also an active remote sensing system which, however, uses electromagnetic wavelengths in the cm range. The radar illustrated in *Fig. 20* is located on the roof of the Institute for Atmospheric Physics of the DLR in Oberpfaffenhofen and has a wavelength of 5 cm. It measures not only the energy reflected from cloud particles, but also the Doppler velocity and the polarisation in two planes of polarisation. The data can be used to determine the contents of liquid water and ice in the clouds, the velocity of the cloud particles moving towards the radar and the geometrical shape of the reflecting cloud particles. *Figure 21*, for example, illustrates the structure of a thunderstorm at a distance of 40 to 80 km from the radar at heights up to 15 km above the ground. The top half of the picture shows the Doppler velocity. The yellow-orange areas are moving away from the radar, while the blue-purple parts of the cloud are moving towards it. The overall movement structure can be reconstructed from the full set of observations, as indicated by the arrows. The lower part of the picture represents the backscattered radar power, this being a measure of the density and extent of rain and snow. This particular example is a thunderstorm with a front with strong gusts and heavy rainfall, 54 km away from the radar. Work is currently focusing on developing radar systems of this kind which will one day be used on satellites. They would allow global observation of precipitation and weather processes with previously unattainable accuracy.

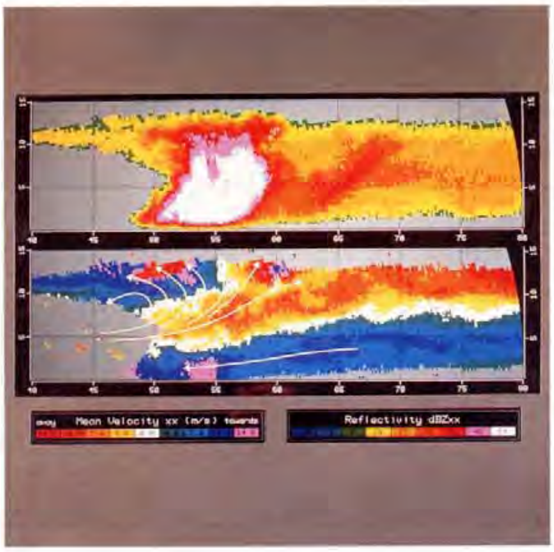


**Fig. 21: Structure of a thunderstorm at a range of 40 to 80 kilometres. Measurements by the DLR radar.**

## Future remote sensing systems

The description of active methods of remote sensing has already addressed the field of future developments. The following is a brief description of some of the systems which are currently in preparation and are to be deployed in the next few years, see *Fig. 22*.

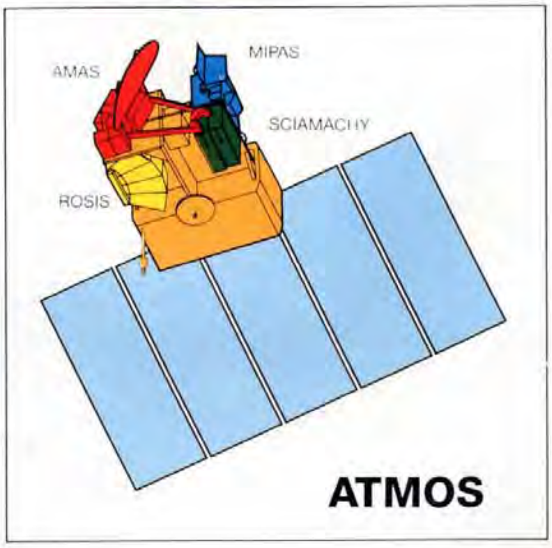
The ERS-1 satellite was launched in July 1991. German institutes have installed a data acquisition station on the Antarctic peninsula which makes it possible to receive data on the Wedell Sea, an area of particular interest for the German Antarctic research community. This station receives SAR data from the ERS-1 within the scope of the Programme for International Polar Ocean Research. *Figure 24* shows this peninsula

**Fig. 22: Future remote sensing systems.**

A Selection with
German participation:

| | |
|---|---|
| ERS-1 | European Remote Sensing Satellite-1 |
| ATMOS | Environmental Monitoring Satellite |
| PRIRODA | Intercosmos Project "Nature" for Soviet Space Station MIR |
| EOS-XSAR | Earth Observation System (NASA, USA)-X-Band SAR |

**Fig. 23: The planned ATMOS satellite.**



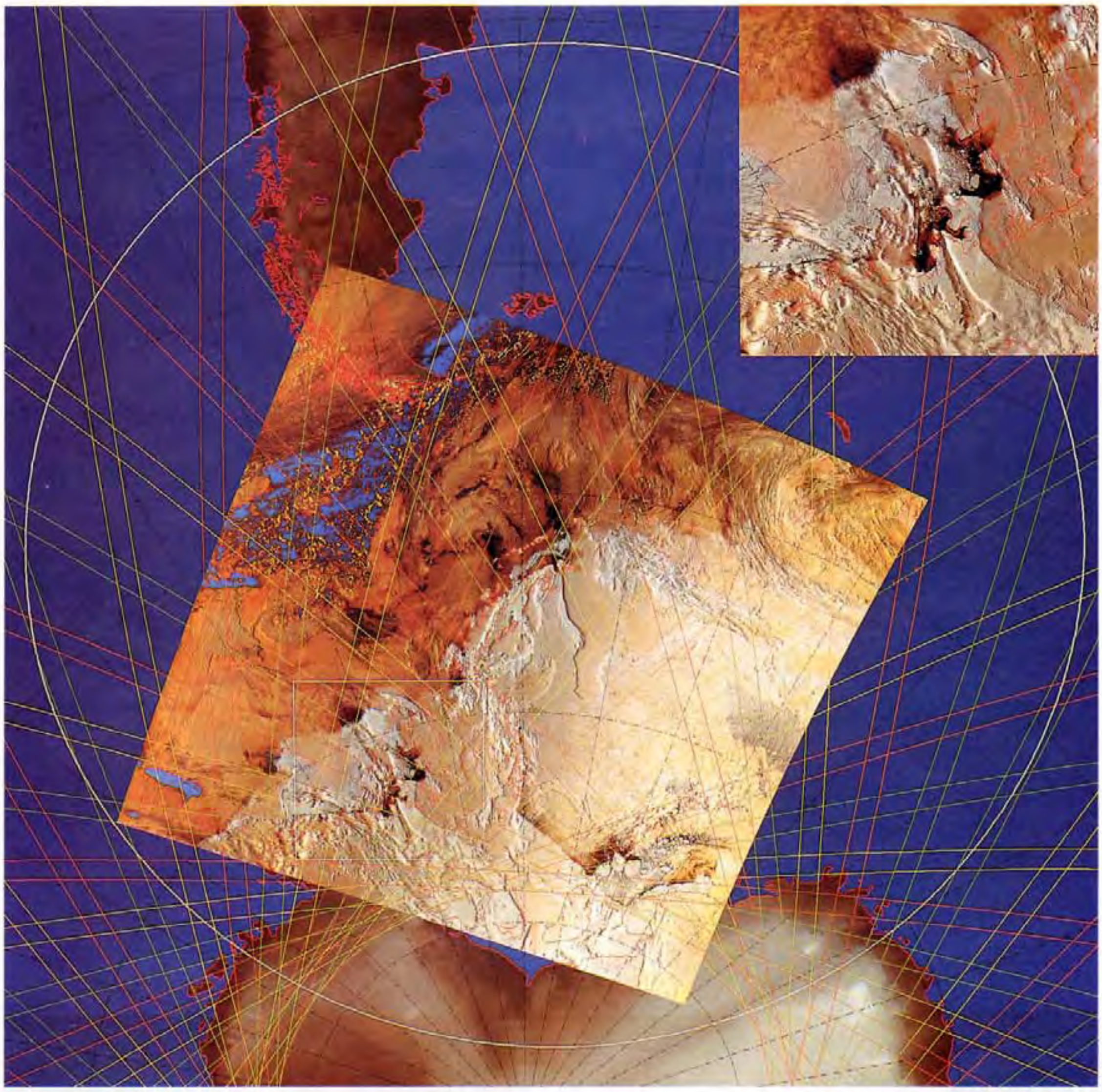


Fig. 24: The Antarctic peninsula is the location of the ERS-1 receiving station operated by the DLR. The ERS-1 reception area is marked by the circle. The individual curves represent the SAR swaths within a three-day period.

and the Southern tip of South America. The ERS-1 reception area is indicated by the circle. The individual curves mark the SAR swaths within a three-day period.

The basis for the picture is an AVHRR scene which was processed in such a way that snow and ice are particularly clear. Even single ice floes can be seen below the thin cover of stratus cloud over the Wedell Sea. ERS-1 will greatly enhance our understanding on the properties of ocean and land surfaces.

Important new or additional information on the composition of the atmosphere, in particular the stratosphere, could be obtained with the aid of the ATMOS sensors *(see Fig. 23)*, which have been proposed and are now being considered for implementation on the polar platforms for Earth observation. They are intended to provide urgently required information for climate and environmental research. The change in the ozone layer is just one of the notable problems in this context. Four sensors have been discussed: AMAS (Advanced Millimeter Wave Atmospheric Sounder), MIPAS (Michelson Interferometer for Passive Atmospheric Sounding), SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Cartography) and ROSIS (Reflective Optics System Imaging Spectrometer). ROSIS *(see Fig. 25)* records land and ocean surfaces, as well as clouds, in up to 128 spectral channels with high spatial resolution.

*Figure 26* shows the X-EOS satellite with a polarimetric multifrequency SAR system. This is a NASA project, for which German and Italian groups are providing an X-band SAR. The project is currently in an advanced study phase. By supplying global SAR observations, it is intended to play a major role in the Mission to Planet Earth. As explained in *Fig. 27*, a system of this kind yields important information for biomass analysis and for detection of wave fields and currents in oceanography, as well as on the nature and extent of the polar ice regions.

The new quality of cooperation between East and West now also offers German institutes the opportunity to use the Soviet orbital station MIR. *Figure 28* shows the basic block of the MIR station, which has been orbiting the Earth at an altitude of 300 to 400 km and an inclination of 51.6° since 1986. One of the four lateral connections shown (inside diameter 800 mm) can be used for coupling various user systems. At the moment, the multisensor PRIRODA system is being prepared for this purpose by the Institute for Radio Engineering and Electronics in Moscow

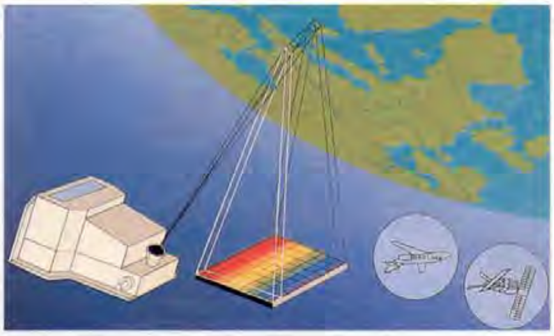


**Fig. 25: ROSIS, an instrument on the ATMOS satellite, is intended to record land and ocean surfaces, as well as clouds, with high spatial resolution.**

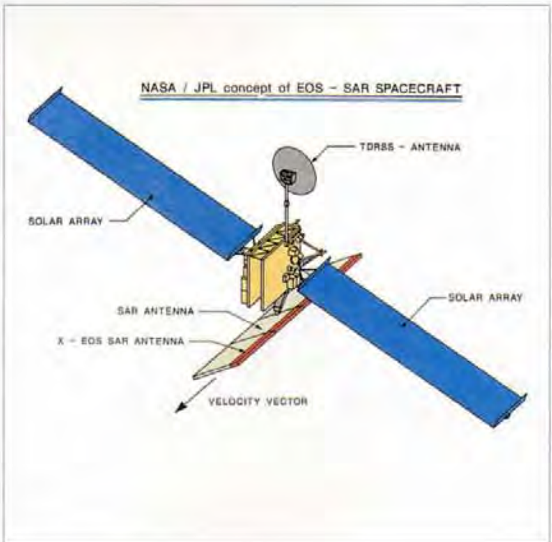



**Fig. 26: The EOS radar satellite.**

**Fig. 27: Tasks of the EOS project.**

- Multipolarization, Electronic beam Steering
- 3 Satellites launched in 5 years intervalls (Firsty 1998–2000)
- German (Italian) Contribution X-Band SAR
- Applications: Ecology, Geology, Hydrology, Oceanography, Glaziology
- Contributes also to VIEW of BIOSPHERE, HYDROLOGIC CYCLE, CARBON DIOXIDE CYCLE etc.

**Fig. 28: Basic block of the Soviet MIR station.**

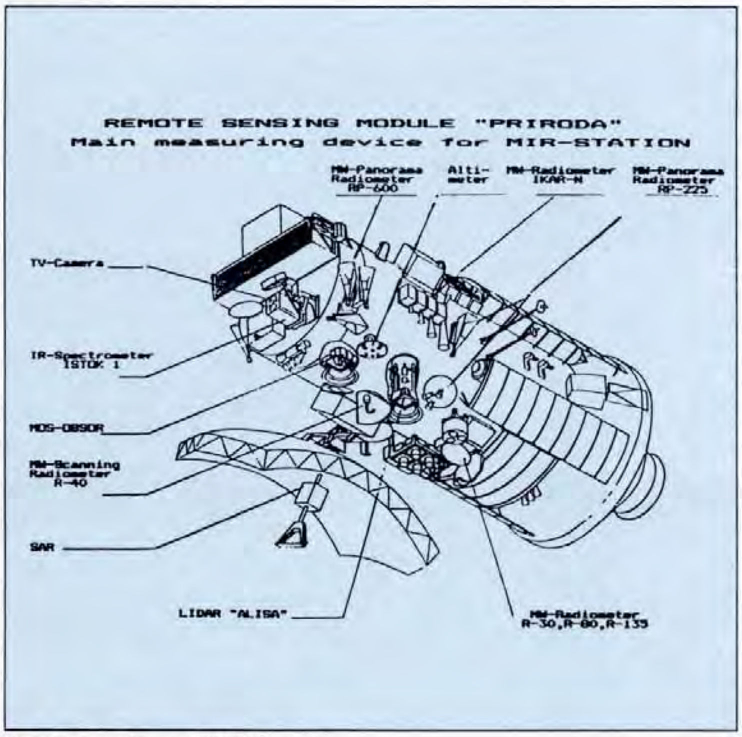



Fig. 29: The multisensor PRIRODA system.

Fig. 30: The basis for future Earth observation.

Basis:

- Available sensors
- Data bases and processing facilities
- Experiences from pilot projects
- New technology
- Challenging applications
- International cooperation

with the participation of all five Interkosmos states *(see Fig. 29)*. The PRIRODA module is roughly 10 m long. The Institute for Cosmic Research in Berlin (now DLR) is providing the MOS optical system. The Russian name PRIRODA means "nature" in English and is certainly a promising name, indicating the growing importance of space-based environmental research.

In summary, it can be said that German institutions have created a strong basis for remote sensing of the Earth. Future work can be based on *(Fig. 30)*

- available sensors,
- data processing systems,
- experience gained in previous pilot projects,
- important and challenging questions, and
- promising technological developments.

In this context, high priority will be given to the application of Earth observation systems for investigating the Earth's environment and climate.

This article is a revised version of a paper presented at the 41st International Astronautical Congress, Dresden, on 9 October 1990. The author would like to thank the numerous colleagues from the DLR and the former Institute for Cosmic Research for their contributions to this work.